

## An active margin across the Adriatic Sea (central Mediterranean Sea)

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(Received January 22, 1992; revised version accepted July 14, 1992)

### ABSTRACT

Favali, P., Funiciello, R., Mattiotti, G., Mele, G. and Salvini, F., 1993. An active margin across the Adriatic Sea (central Mediterranean Sea). In: A.G. Green, A. Kröner, H.-J. Götze and N. Pavlenkova (Editors), *Plate Tectonic Signatures in the Continental Lithosphere*. *Tectonophysics*, 219: 109–117.

New seismological and structural data from the central Adriatic–Gargano promontory area demonstrate that the current models of an aseismic and slightly deformed Adriatic block have to be revised. A seismically active deformational belt is mapped along two main fault systems, the Tremiti Islands and Mattinata faults. Moreover, geologic and geophysical evidence suggests that a more extensive lithospheric boundary may cut across the central Italian peninsula to the Tyrrhenian basin.

### Introduction

The principal aim of this paper is to present new evidence that supports the hypothesis of a tectonically active boundary across the Adriatic basin. The central Mediterranean area is characterized by continental blocks, basins and orogenic belts that are associated with the collision of the African and the European plates (McKenzie, 1972). At the latitude of the Italian peninsula several geodynamic units can be recognized (Fig. 1a). From west to east they are: the Sardinia–Corsica block, which is a fragment of European lithosphere; the Tyrrhenian extensional basin; the Apennine thrust system; and the Adriatic block, which acted as a foreland for both the Apennines to the southwest and the Dinarides to the north-east (Parotto and Pratlun, 1981). The Adriatic block plays an important role in the evolution of

the central Mediterranean area, with its continental lithosphere (Suhadolc and Panza, 1989) underthrusting the strongly deformed Apennines

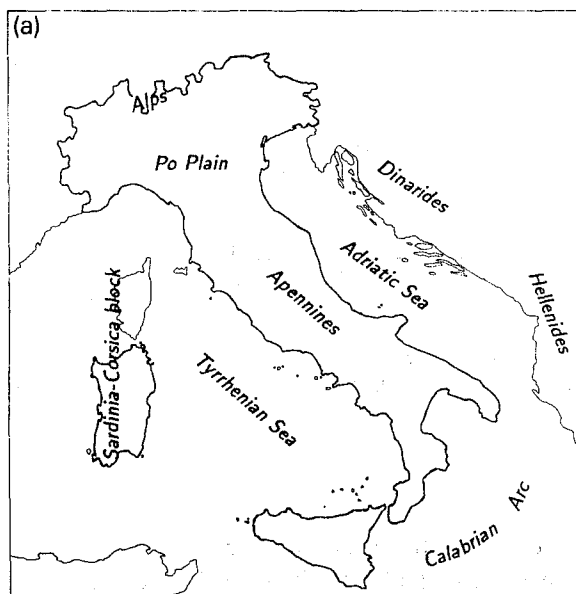


Fig. 1a. Main geodynamic units at the latitude of the Italian peninsula.

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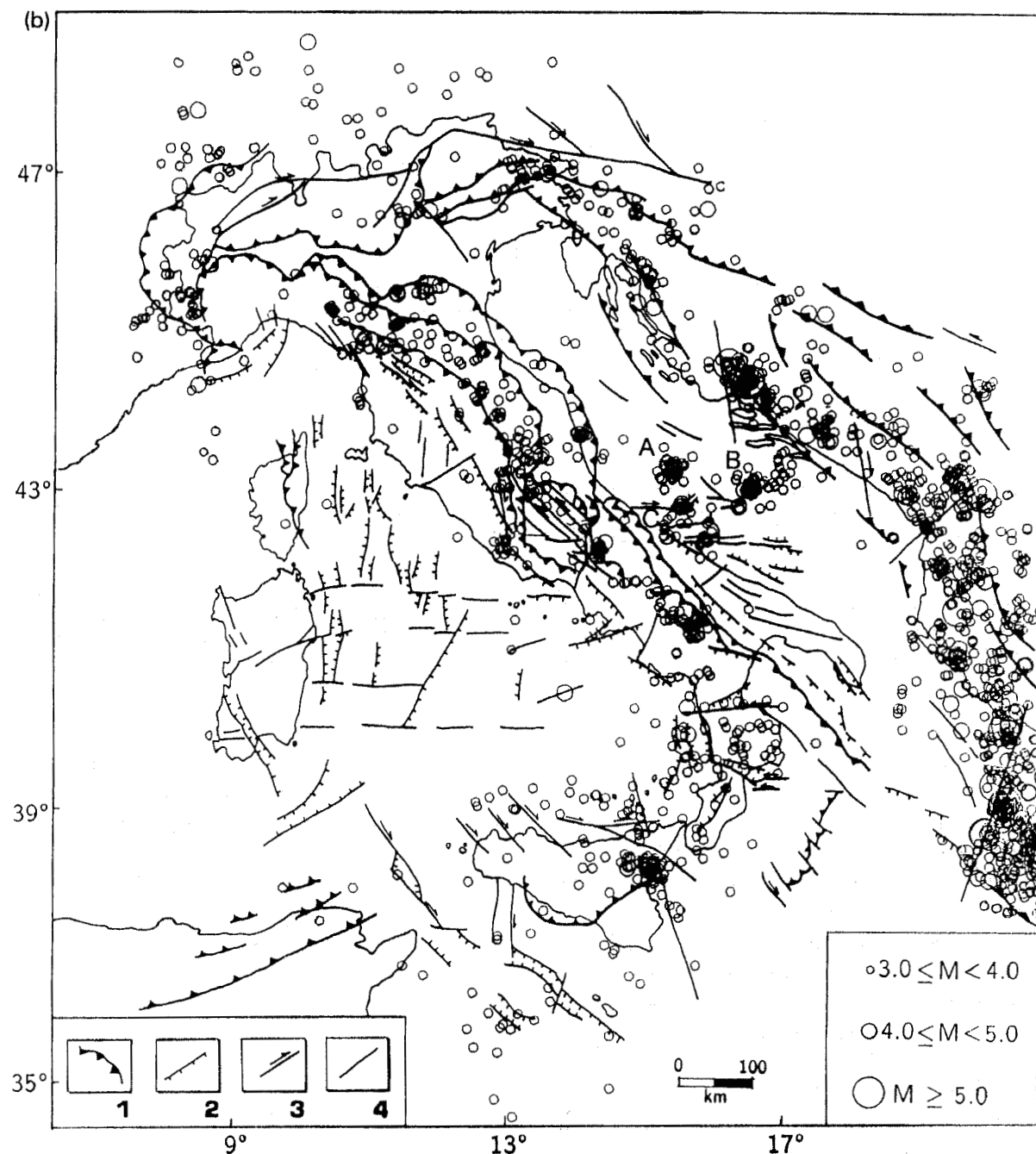


Fig. 1b. Geodynamic framework (modified after Bigi et al., 1989) and recent seismicity (ING, 1990) of the Italian peninsula and surrounding areas. A: 1986–87; B: 1988; C: 1989–90 indicate the Adriatic seismic sequences. Legend: 1 = thrust; 2 = normal fault; 3 = strike-slip fault; 4 = sub-vertical fault.

to the west, the Southern Alps to the north, and the Dinaric–Hellenic chain to the east-southeast (Malinverno and Ryan, 1986; Moretti and Royden, 1988).

Whether the Adriatic block represents a promontory of the African plate (e.g., Argand, 1924; Dercourt, 1972; Auboin, 1976; Channell et al., 1979; D'Argenio and Horváth, 1984) or a

distinct microplate (e.g., Dewey et al., 1973; Biji-Duval et al., 1977; Vandenberg, 1979; Hsü, 1982; Manzoni and Vandenberg, 1982) with margins identified on the basis of the seismicity patterns (e.g., Lort, 1971), is rather controversial. Regardless of this controversy, some authors (e.g., Mantovani et al., 1985; Anderson and Jackson, 1987b) continue to interpret of the Adriatic block as a single, rigid, almost aseismic block.

In our opinion, there are several lines of evidence which indicate that fundamental lithospheric changes may occur between the northern and the southern Adriatic Sea. From a morphological point of view the Adriatic basin is quite complex. North of 42°N it is a shallow-water basin with a maximum depth of about 200 m, whereas to the south there is an abrupt deepening to depths greater than 1200 m (Giorgetti and Mosetti, 1969). At approximately the same latitude, a positive Bouguer gravity anomaly corresponds to the Gargano promontory (Finetti and Morelli, 1973). The maximum Bouguer gravity anomaly (over +50 mGal) is confined to the region of the Tremiti Islands Fault to the north and the Mattinata Fault to the south (Finetti, 1982; Finetti et al., 1987). The Gargano promontory itself is a structurally high area where Mesozoic strata rise to around 1000 m above sea level, and the Tremiti Islands represent a structural high of less importance. The depth to the lithosphere/asthenosphere boundary has a very strong gradient at the same general location (Suhadolc and Panza, 1989). The structural data (Funicello et al., 1988, 1991) and the results of recent seismic analyses (Console et al., 1989, 1993; Favali et al., 1990) support the existence of complex heterogeneities or lithospheric breaks in this area.

### Seismic data

Recent seismic data give a picture of the present state of stress in the region (ING, 1990). Contrary to current models of an essentially aseismic Adriatic block, three important seismic sequences have occurred offshore the Gargano promontory during the past five years (sequence A in 1986–87, B in 1988, and C in 1989–90; see Fig. 1b). These sequences were relocated using

data collected by the new Italian Telemetered Seismic Network (ITSN) and by other Italian, Albanian and Yugoslavian stations (Console et al., 1992). The epicenters of each of the three sequences relate to seismogenic structures that are less than about 20 km long, compatible with the source dimensions of the three main shocks (1986,  $m_b = 4.2$ ; 1988,  $m_b = 5.3$ ; 1989,  $m_b = 4.7$ ). The epicenters of the A and B sequences are aligned with the trend of the Tremiti Islands Fault. The earthquake data set shown in Figure 1b (1986–1990 period) represents events with magnitudes greater than 3.0, the minimum magnitude required for good azimuthal recording over the past few years in this region.

In the middle Adriatic area, where the seismic sequences occurred, only one reliable focal mechanism solution is available (1988,  $m_b = 5.3$ ). The two methods that have been used to determine the fault parameters, one based on the “double-couple” model and the other on centroid moment tensor calculations (Dziewonski et al., 1981) yield similar results for teleseismic events. Both solutions display strike-slip faulting with thrust components, but the strike-slip component is more evident than the thrust component in the “double-couple” result (Fig. 1c; Console et al., 1993). These solutions are compatible with the proposed

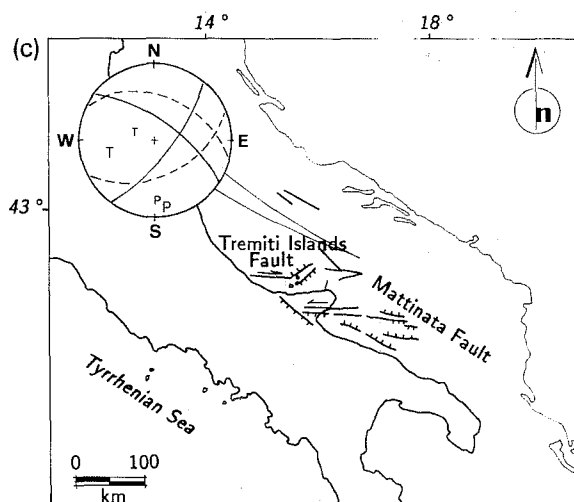


Fig. 1c. Detail of the middle Adriatic area, the available focal mechanism solutions of the 1988 main shock ( $m_b = 5.3$ ) are shown, the solid line is the “double-couple” result and the hatched line is the centroid moment tensor calculation (Console et al., 1993).

strike-slip deformations across the two regional Tremiti Islands and Mattinata fault systems, which continue for many tens of kilometres from the land toward the sea (Finetti, 1982; Finetti et al., 1987).

### Structural data

Structural studies of the Gargano promontory and Tremiti Islands support the geophysical evidence for a major horizontal shear zone. The geographic location of these two areas and the Latium–Abruzzi platform, mentioned in the following discussion, are shown in Figure 2. Analysis at 95 locations on the Gargano promontory have resulted in nearly 400 deformation attitude estimates (mainly fault systems; Funicello et al., 1988). From the Eocene to the present, this sector of the Adriatic block experienced uplift along a series of near-vertical faults that trend E–W and NW–SE. Most of these faults show evidence of early dip-slip movements compatible with uplift, and subordinate oblique to strike-slip motion due to younger reactivation. Our studies in the southern zone have confirmed the presence of a major E–W fault zone, the Mattinata Fault, and unlike previous studies (Guerricchio, 1986; Ortolani and Pagliuca, 1987), showed clear evidence of left-lateral strike-slip kinematics. The main faulting pattern based on our structural study is shown in Figure 3.

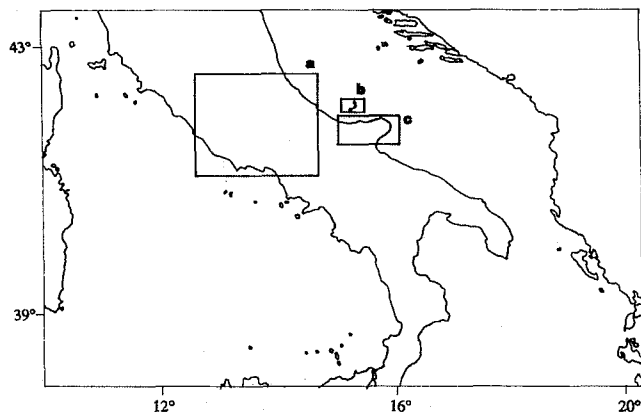


Fig. 2. Geographic location of the structural study areas: *a* = Latium–Abruzzi platform domain (central Apennines); *b* = Tremiti Islands; *c* = Gargano promontory.

In the western and eastern sectors of this fault system there is evidence of major strike-slip movement together with some indications for a left-lateral sense of movement (locations *a* and *d* in Fig. 3). Further evidence for left-lateral shear is obtained in the central sector, where a series of bends of the main fault produce significant and rather spectacular deformational patterns. Near S. Marco in Lamis (location *b* in Fig. 3), clockwise bending together with a partial transfer of the displacement to a NW–SE-trending fault (re-activated with left-lateral strike-slip movement) has produced a series of compressional deformations, including the near-vertical tilting of strata and minor reverse faulting, which are diagnostic of ENE–WSW compression (see the projection for location *b* in Fig. 3). The opposite deformational style was found along the Pantano S. Egidio depression (location *c* of Fig. 3), where there is a counterclockwise bend of the Mattinata Fault. The bending may result in pull-apart tectonism, perhaps explaining the present-day depression there. Structural analysis of this sector suggests the presence of E–W and NW–SE oblique-slip to dip-slip normal faults dipping towards the depression, with second-order left-lateral strike-slip faults that trend E–W (see the projection for location *c* in Fig. 3). The Eocene-age units have been displaced by these faults. Even younger activity is suspected on the basis of the large morphological contrasts, which are almost exclusively related to heavily fractured limestones in fault zones. Offshore seismic profiles show the continuation of the Mattinata Fault and demonstrate offsets of still younger units (De' Dominicis and Mazzoldi, 1987). Further details on the results of the inland structural study can be found in Funicello et al. (1988, 1991). Our structural results together with other geophysical and geological data lead to the development of a model in which the Gargano promontory is a push-up structure generated by the interaction of an E–W-trending left-lateral strike-slip fault zone to the south, and an E–W- to NE–SW-trending right-lateral strike-slip fault zone to the north.

Although the results of the structural study across the major Tremiti Islands (24 locations and 170 measured attitudes) were less definitive, be-

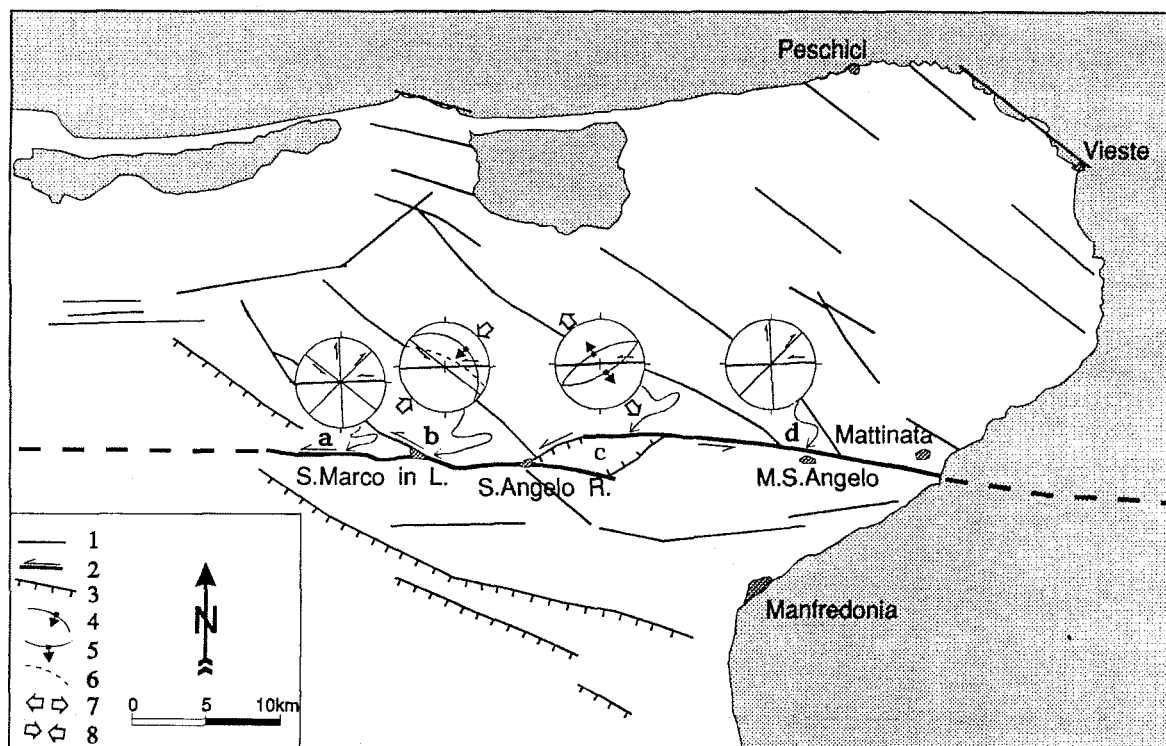


Fig. 3. Schematic map of the Gargano promontory that results from our structural study. Circles represent Schmidt projections (lower hemisphere) of the main faults along the Mattinata fault system. 1 = main sub-vertical regional faults; 2 = as for 1 but with a prevailing strike-slip component; 3 = as for 1 but with predominant dip-slip component; 4 = reverse fault systems (in the projections); 5 = normal fault systems (in the projections); 6 = bedding; 7 = extensional direction as derived by fault analysis; 8 = compressional direction as derived by fault analysis.

cause of limited outcrops, they showed a similar tectonic style (Fig. 4; Montone and Funicicello, 1989). We suspect that this archipelago repre-

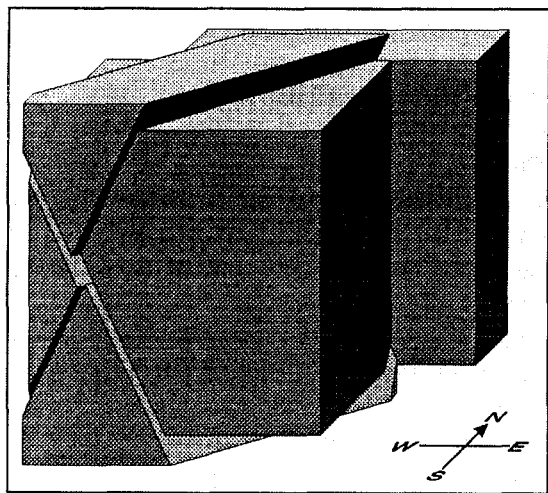


Fig. 4. Block-diagram showing the tectonic environment of the Tremiti Islands.

sents the top of a NE-SW elongated structural high located along an E-W to NE-SW regional strike-slip fault zone. Such a proposal is supported by interpretations of marine seismic reflection data (Finetti et al., 1987). The geometric relationships between the structural high and the regional shear zone requires right-lateral movement for the latter.

## Discussion

All available data support the existence of a roughly E-W-trending deformational belt of lithospheric importance in the central Adriatic basin. This belt has experienced recent activity, as inferred from structural and seismicity data, and it may be an active zone of decoupling between the northern and the southern Adriatic blocks. A possible westward prolongation of this active margin through the Apennines is marked by im-

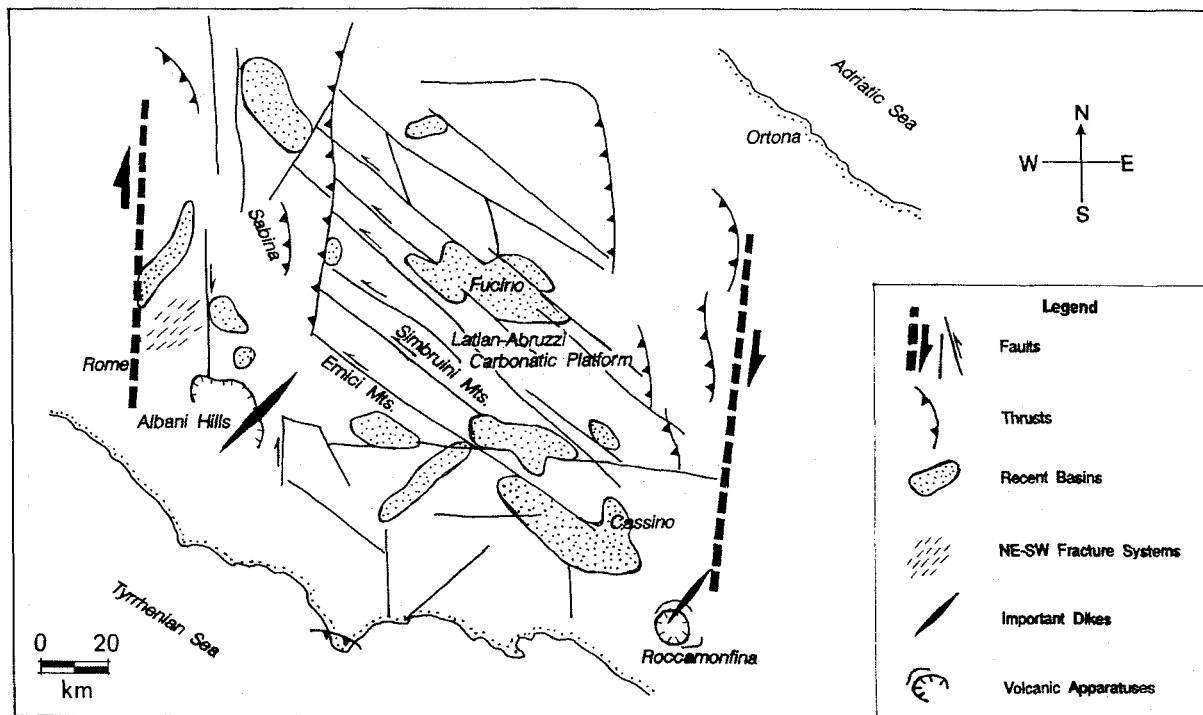


Fig. 5. Schematic structural map of the Latium-Abruzzi carbonatic platform domain.

portant structures (Fig. 5). Regional extension has resulted in the subdivision of the Latium-Abruzzi carbonatic platform into a series of NW-SE-trending elongated blocks (Salvini, 1992), whereas on both the eastern and western edges of the platform there are two generally N-S-trending tectonic discontinuities (Ortona-Roccamonfina and Ancona-Anzio "faults") along which evidence for recent right-lateral strike-slip movements has been found (Alfonsi et al., 1991a,b). Between the two discontinuities, field evidence has shown left-lateral strike-slip motions along the boundaries of the previously described blocks (Montone and Salvini, 1991). This tectonic setting is generally compatible with the block rotation models proposed by McKenzie and Jackson (1983; and correction, 1984) and Nur et al. (1986).

The above mentioned N-S discontinuities are probably the boundaries of a transition zone dividing a northern province characterized by crustal contamination of magma from a southern province characterized by subduction-enriched

mantle sources, as inferred from the isotopic features and trace elements (Serri, 1990). This differentiation of two magmatic provinces is also observed in the Tyrrhenian basin, where they are separated by a discontinuity along  $41^{\circ}\text{N}$  (Fig. 6; Selli et al., 1977; Wezel, 1985; Finetti and Del Ben, 1986; Sartori et al., 1989). This boundary has been interpreted recently as a kind of transform fault which, since late Tortonian times, has separated the Tyrrhenian Sea into two sectors with different tectonic histories (Patacca et al., 1990). In the northern sector, partial melting of sub-crustal bodies and a positive thermal flux along the Italian coastline are observed (Mongelli et al., 1989), whereas the southern sector is characterized by an active subduction process (e.g., Amato et al., 1993), deep seismicity (e.g., Caputo et al., 1970, 1972; Anderson and Jackson, 1987a; Giardini and Velonà, 1991) and potassic volcanism (Barberi et al., 1973).

The model proposed in Figure 6 attempts to genetically connect the various deformation zones in the region. Within this framework, the strike-

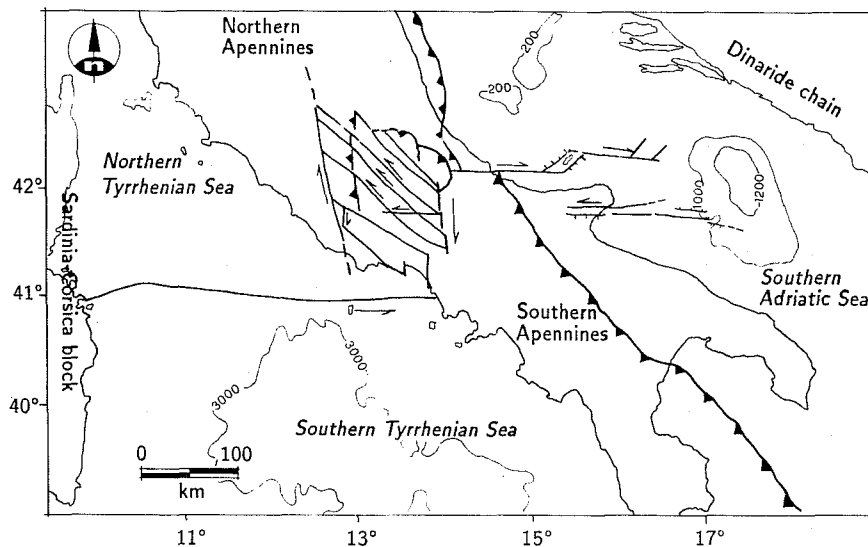


Fig. 6. Proposed geodynamic model. For an explanation of the symbols see Fig. 1; the maximum depth isobaths are drawn.

slip area of the central Apennines is a surficial effect of westward offsets to the south of the Adriatic lithospheric margin.

## Conclusions

The Italian area south of the Alps–Po Plain is divided into three main lithospheric units: the Adriatic block to the east, which is a foreland-like structure with respect to the Apennines and the Dinarides, the Apennine mountains and the Tyrrhenian extensional basin to the west. Earthquakes recorded (1986–1990) within the Adriatic basin suggest the existence of an active zone in the central Adriatic area. This hypothesis is supported by meso-structural data collected from the Gargano promontory and the Tremiti Islands. Field surveys of the central Apennines confirm recent major strike-slip deformations that are superimposed on regional extensional structures. Moreover, geochemical data from volcanic rocks of the Tyrrhenian area point to the occurrence of a lithospheric discontinuity at about the 41°N, which separates a recent, oceanic and seismically/volcanically active structure to the south from the northern area. Structures within the three main lithospheric units can be connected along an E–W zone.

## Acknowledgements

The authors wish to thank Enzo Boschi for his encouragement, Alan G. Green and an anonymous reviewer for revising the text. Appreciation is expressed to Daniela Riposati for drawing some of the figures.

## References

- Alfonsi, L., Funiciello, R., Mattei, M., Girotti, O., Maiorani, A., Preite Martinez, M., Trudu, C. and Turi, B., 1991a. Structural and geochemical features of the Sabina strike-slip fault (central Apennines). *Boll. Soc. Geol. Ital.*, 110: 217–230.
- Alfonsi, L., Funiciello, R. and Mattei, M., 1991b. Strike-slip tectonics in the Sabina area. *Boll. Soc. Geol. Ital.*, 110: 481–488.
- Amato, A., Alessandrini, A. and Cimini, G.B., 1993. Teleseismic-wave tomography of Italy. In: H.M. Iyer and K. Hirahara (Editors), *Seismic Tomography*. Chapman and Hall, London, pp. 361–396.
- Anderson, H. and Jackson, J., 1987a. The deep seismicity of the Tyrrhenian Sea. *Geophys. J.R. Astron. Soc.*, 91: 613–637.
- Anderson, H. and Jackson, J., 1987b. Active tectonics of the Adriatic region. *Geophys. J.R. Astron. Soc.*, 91: 937–983.
- Argand, E., 1924. *La Tectonique de l'Asie*. *Proc. Int. Geol. Congr.*, 13: 171–372.
- Auboin, J., 1976. Alpine tectonics and plate tectonics: thoughts about the Eastern Mediterranean. In: D.V. Ager and M.

- Brooks (Editors), *Europe from Crust to Core*. Wiley, London, pp. 143–158.
- Barberi, F., Gasparini, P., Innocenti, F. and Villari, L., 1973. Volcanism of the Southern Tyrrhenian Sea and its geodynamic implications. *J. Geophys. Res.*, 78: 5221–5232.
- Bigi, G., Castellarin, A., Catalano, R., Coli, M., Cosentino, D., Dal Piaz, G.V., Lentini, F., Parotto, M., Patacca, E., Praturlon, A., Salvini, F., Sartori, R., Scandone, P. and Vai, G.B., 1989. Synthetic Structural-Kinematic Map of Italy (1:2,000,000). C.N.R. - P.F.G., Roma.
- Biju-Duval, B., Dercourt, J. and Le Pichon, X., 1977. From the Tethys Ocean to the Mediterranean Seas: a plate tectonic model of the evolution of the Western Alpine system. In: B. Biju-Duval and L. Montadert (Editors), *The Structural History of the Mediterranean Basins*. Technip, Paris, pp. 143–167.
- Caputo, M., Panza, G.F. and Postpischl, D., 1970. Deep structure of the Mediterranean basin. *J. Geophys. Res.*, 75: 4919–4923.
- Caputo, M., Panza, G.F. and Postpischl, D., 1972. New evidences about deep structure of the Lipari arc. *Tectonophysics*, 15: 219–231.
- Channell, J.E.T., D'Argenio, B. and Horváth, F., 1979. Adria, the African promontory in Mesozoic Mediterranean paleogeography. *Earth-Sci. Rev.*, 15: 213–272.
- Console, R., Di Giovambattista, R., Favali, P. and Smriglio, G., 1989. Lower Adriatic Sea seismic sequence (January 1986): spatial definition of the seismogenic structure. *Tectonophysics*, 166: 235–246.
- Console, R., Di Giovambattista, R., Favali, P., Presgrave, B.W. and Smriglio, G., 1993. Seismicity of the Adriatic microplate. *Tectonophysics*, 218: 343–354.
- D'Argenio, B. and Horváth, F., 1984. Some remarks on the deformation history of Adria, from the Mesozoic to the Tertiary. *Ann. Geophys.*, 2: 143–146.
- De' Dominicis, A. and Mazzoldi, G., 1987. Interpretazione geologico-strutturale del margine orientale della piattaforma Apula. *Mem. Soc. Geol. Ital.*, 38: 163–176.
- Dercourt, J., 1972. The Canadian Cordillera, the Hellenides, and the sea-floor spreading theory. *Can. J. Earth Sci.*, 9: 709–743.
- Dewey, J.F., Pitman, W.C., Ryan, W.B.F. and Bonnin, J., 1973. Plate tectonics and the evolution of the Alpine system. *Geol. Soc. Am. Bull.*, 84: 3137–3180.
- Dziewonski, A.M., Chou, T.A. and Woodhouse, J.H., 1981. Determination of earthquakes source parameters from waveform data for studies of global and regional seismicity. *J. Geophys. Res.*, 86: 1825–1852.
- Favali, P., Mele, G. and Mattiotti, G., 1990. Contribution to the study of the Apulian microplate geodynamics. *Mem. Soc. Geol. Ital.*, 44: 71–80.
- Finetti, I., 1982. Structure, stratigraphy and evolution of Central Mediterranean. *Boll. Geofis. Teor. Appl.*, 24: 247–312.
- Finetti, I. and Del Ben, A., 1986. Geophysical study of the Tyrrhenian opening. *Boll. Geofis. Teor. Appl.*, 38: 75–155.
- Finetti, I. and Morelli, C., 1973. Geophysical exploration of the Mediterranean Sea. *Boll. Geofis. Teor. Appl.*, 15: 263–341.
- Finetti, I., Bricchi, G., Del Ben, A., Pipan, M. and Xuan, Z., 1987. Geophysical study of the Adria plate. *Mem. Soc. Geol. Ital.*, 40: 335–344.
- Funiciello, R., Montone, P., Salvini, F. and Tozzi, M., 1988. Caratteri strutturali del Promontorio del Gargano. *Mem. Soc. Geol. Ital.*, 41 (in press).
- Funiciello, R., Montone, P., Parotto, M., Salvini, F. and Tozzi, M., 1991. Geodynamical evolution of an intra-orogenic foreland: The Apulia case history (Italy). *Boll. Soc. Geol. Ital.*, 110: 419–425.
- Giardini, D. and Velonà, M., 1991. The deep seismicity of the Tyrrhenian Sea. *Terra Nova*, 3: 57–64.
- Giorgetti, F. and Mosetti, F., 1969. General morphology of the Adriatic Sea. *Boll. Geofis. Teor. Appl.*, 11: 49–56.
- Guerricchio, A., 1986. Esempi di bacini di pull-apart nel Gargano (Puglia Settentrionale). *Geol. Appl. Idrogeol.*, 21: 25–36.
- Hsü, K.J., 1982. Alpine–Mediterranean geodynamics: past, present and future. In: H. Berckhemer and K.J. Hsü (Editors), *Alpine–Mediterranean Geodynamics*. Am. Geophys. Union - Geol. Soc. Am., *Geodyn. Ser.*, 7: 7–14.
- Istituto Nazionale di Geofisica (ING), 1990. Seismic bulletin (1986–1990). Roma.
- Lort, J.M., 1971. The tectonics of the Eastern Mediterranean: A geophysical review. *Rev. Geophys. Sp. Phys.*, 9: 189–216.
- Malinverno, A. and Ryan, W.B.F., 1986. Extension of the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking lithosphere. *Tectonics*, 5: 227–245.
- Mantovani, E., Babbucci, D. and Farsi, F., 1985. Tertiary evolution of the Mediterranean region: outstanding problems. *Boll. Geofis. Teor. Appl.*, 26: 67–88.
- Manzoni, M. and Vandenberg, J., 1982. Perityrrhenian paleomagnetic data and the setting of the Calabrian arc. In: E. Mantovani and R. Sartori (Editors), *Structure, Evolution and Present Dynamics of the Calabrian Arc*. *Earth Evol. Sci.*, 3: 181–186.
- McKenzie, D., 1972. Active tectonics of the Mediterranean region. *Geophys. J.R. Astron. Soc.*, 30: 109–185.
- McKenzie, D. and Jackson, J., 1983. The relationship between strain rates, crustal thickening, paleomagnetism, finite strain and fault movements within a deforming zone. *Earth Planet. Sci. Lett.*, 65: 182–202 and correction of above *ibid.*, 1984, 70: 444.
- Mongelli, F., Zito, G., Ciaranfi, N. and Pieri, P., 1989. Interpretation of heat flow density of the Apennine chain, Italy. *Tectonophysics*, 164: 267–280.
- Montone, P. and Funiciello, R., 1989. Elementi di tettonica trascorrente alle Isole Tremiti (Puglia). *Rend. Soc. Geol. Ital.*, 12: 7–12.
- Montone, P. and Salvini, F., 1991. Evidences of strike-slip tectonics in the Apenninic chain near Tagliacozzo (L'Aquila), Abruzzi, Central Italy. *Boll. Soc. Geol. Ital.*, 110: 617–619.



- Moretti, I. and Royden, L., 1988. Deflection, gravity anomalies and tectonics of doubly subducted continental lithosphere: Adriatic and Ionian Seas. *Tectonics*, 7: 875–893.
- Nur, A.M., Ron, H. and Scotti, O., 1986. Fault mechanisms and the kinematics of block rotation. *Geology*, 14: 746–749.
- Ortolani, F. and Pagliuca, S., 1987. Il Gargano (Italia Meridionale): un settore di “avampaese” deformato tra le catene appenninica e dinarica. *Mem. Soc. Geol. Ital.*, 38: 205–224.
- Parotto, M. and Praturlon, A., 1981. Structural sketch of the Middle–Eastern Mediterranean area. C.N.R.-P.F.G., Publ. no. 269, G.E.O., Roma.
- Patacca, E., Sartori, R. and Scandone, P., 1990. Tyrrhenian basin and Apenninic arcs: kinematic relations since late Tortonian times. In: “La Geologia italiana degli anni ‘90”, 75° Meeting Ital. Geol. Soc. (invited paper), pp. 102–107.
- Salvini, F., 1992. Tettonica a blocchi in settori crostali superficiali: modellizzazione ed esempi da dati strutturali in Appennino Centrale. *Studi Geol. Camerti, Spec. Iss.*, 1991/2: 237–248.
- Sartori, R. and ODP Leg 107 Scientific Staff, 1989. Drillings of ODP Leg 107 in the Tyrrhenian Sea: Tentative basin evolution compared to deformations in the surrounding chains. In: A. Boriani, M. Bonafede, G.B. Piccardo and G.B. Vai (Editors), *The Lithosphere in Italy*. Acc. Naz. Lincei, Roma, 80: 139–156.
- Selli, R., Lucchini, F., Rossi, P.L., Savelli, C. and Del Monte, M., 1977. Dati petrologici, petrochimici e radiometrici sui vulcani centro-tirrenici. *G. Geol.*, 42: 221–246.
- Serri, G., 1990. Neogene–Quaternary magmatism of the Tyrrhenian region: characterization of the magma sources and geodynamic implications. *Mem. Soc. Geol. Ital.*, 44: 219–242.
- Suhadolc, P. and Panza, G.F., 1989. Physical properties of the lithosphere–asthenosphere system in Europe from geophysical data. In: A. Boriani, M. Bonafede, G.B. Piccardo and G.B. Vai (Editors), *The Lithosphere in Italy*. Acc. Naz. Lincei, Roma, 80: 15–40.
- Vandenberg, J., 1979. Reconstruction of the Western Mediterranean area for the Mesozoic and Tertiary timespan. *Geol. Mijnbouw*, 58: 153–160.
- Wezel, F.C., 1985. Structural features and basin tectonics of the Tyrrhenian Sea. In: D.J. Stanley and F.C. Wezel (Editors), *Geological Evolution of the Mediterranean Basin*. Springer-Verlag, New York, pp. 153–194.